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Research Progress in the Application of Chinese Herbal Medicines in Aquaculture: A Review

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ABSTRACT

Due to increasing safety concerns regarding human consumption of fish products, an increasing number of medicinal chemicals are prohibited from use in aquaculture. As a result, Chinese herbal medicines are being increasingly used, coining the use of the term "green medicine." Research shows that Chinese herbal medicines have many beneficial effects on fish, including growth promotion, enhancement of disease resistance, and improvement in meat quality. Many effective ingredients have been discovered in Chinese herbal medicines, which function to promote feed intake, improve meat flavor, and increase digestive enzyme activity. They also regulate and participate in processes that improve the specific and non-specific immunity of fish; however, the composition of Chinese herbal medicines is very complex and it is often difficult to identify the effective ingredients. This article reviews the latest research and application progress in Chinese herbal medicines regarding growth and feed utilization, immunity and disease resistance, and the meat quality of cultured fish. It also discusses research on the chemical constituents of classical Chinese medicinal herbs and problems with the application of Chinese herbal medicines in fish culture. This article concludes by proposing that future studies on Chinese herbal medicines should focus on how to cheaply refine and extract the effective ingredients in classical Chinese medicinal herbs, as well as how to use them efficiently in aquaculture.

1. Introduction

Chinese herbal medicines have been used in China for thousands of years and are generally recognized as being natural and safe [1]. These herbs contain many effective ingredients, including polysaccharides, alkaloids, flavonoids, volatile oils, organic acids, and tannins, as well as nutrients such as amino acids, carbohydrates, minerals, and vitamins [2]. Studies have shown that these effective ingredients can increase appetite [3,4], promote metabolism, accelerate the synthesis of proteins [5,6], increase enzyme activity [7], improve immunity [8,9], increase disease resistance [10], and enhance meat quality [11,12] (Fig. 1).

Chinese herbal medicines have long been applied as attractants, growth promoters [13], antibacterial agents, and immunoprophylactic agents in aquaculture [14], and are considered to be effective alternatives to antibiotics, chemicals, vaccines, and other synthetic compounds [15]. In recent years, many studies have been conducted on the further application of Chinese medicinal herbs because of their advantages of being natural, innocuous, easy to prepare, and inexpensive, and because they have few side effects for either the fish or the environment [16]. Chinese herbal medicines can be administered as a whole plant, as parts of a plant (leaf, root, or

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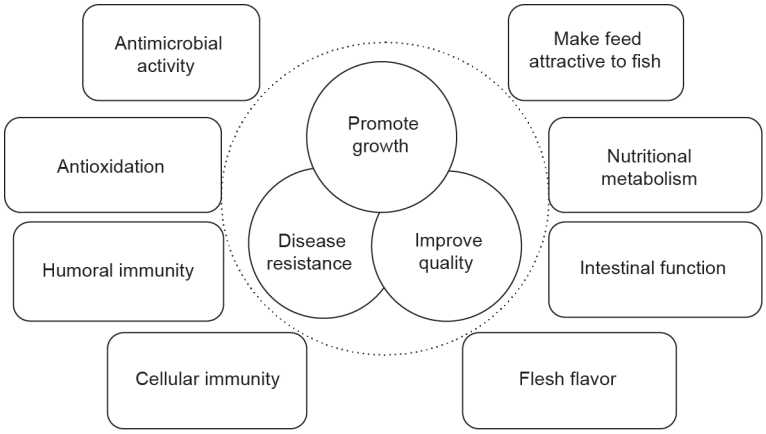


Fig. 1. Roles and main action mechanisms of Chinese herbal medicines when used on fish.

seed), or as extract compounds used either alone or in combination with other feed additives; they can be applied in the feed or via the immersion of fish in treated water [17]. However, the chemical constituents of Chinese herbal medicines are very complex and their biological activities are not always consistent. Additional investigations are needed to reveal the chemical structures and functional mechanisms of Chinese herbal medicines [18,19]. This study expounds on research progress in the extraction and purification of the effective ingredients of Chinese herbal medicine, introduces the chemical structures of some of the main effective ingredients in Chinese herbal medicines, and reviews the effects of Chinese herbal medicines on fish culture.

2. Studies on the chemical constituents of classical Chinese herbal medicines

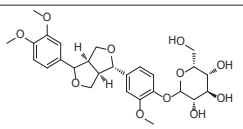
The chemical constituents of Chinese herbal medicines are complex, diverse, and found in trace amounts, so it is very difficult to analyze and identify the effective ingredients in Chinese herbal medicines. More and more Chinese herbal medicines have been studied in detail and their key effective ingredients have been identified with the development of new analytical technologies (Table 1).

In 2001, ultrasound technology was used to extract alkaloids, flavonoids, anthraquinone, and polysaccharides from Chinese medicinal herbs [20]. In 2004, supercritical fluid chromatography became an effective method for analyzing large molecular ingredients such as phospholipids, triglycerides, and carotenoids. Supercritical fluid technology has the advantage of high selectivity, which allows it to precisely analyze the effective ingredients in Chinese medicinal herbs when combined with technologies such as gas chromatography, high-performance liquid chromatography (HPLC), and gas chromatography/mass spectrometry [21]. In 2005, the development of capillary electrophoresis technology, along with the development of other analytical technologies, provided a method to separate the trace effective ingredients in Chinese herbal medicines [22].

In 2006, molecular distillation technology was applied to extract the volatile oils of *Atractylodes macrocephala*, *Allium sativum*, *Angelica sinensis*, and *Forsythia suspensa* [23]. In 2008, membrane extraction technology, high-speed counter-current chromatography separation technology, and molecular imprinting separation technology were used for herb chemical analysis [24]. In 2009, researchers found that cellulase could improve the extraction rate of polysaccharides [25]. Fourier-transform ion cyclotron resonance mass spectrometry/sequential mass spectrometry technology combined with HPLC was later used to obtain accurate high-quality data. An accurate mass obtained by high-resolution mass spectrometry, comprised of multistage mass spectrometry fragmentation information and mass spectrometry, was used to analyze and identify the ingredients of *Epimedium brevicornu* [26]. In 2012, ultraviolet spectrophotometry was used to identify and quantify the effective ingredients in Chinese medicinal herbs, and the concentrations of various polysaccharides, alkaloids, flavonoids, and volatile oils were determined [27]. In 2013, researchers used imidazole-based ionic liquid as the extractant to obtain quercetin and kaempferol from *Cedrela sinensis* and *Rosae sinensis* using a microwave extraction method [28].

In 2014, three principal components and the corresponding principal component equations were obtained by principal component analysis from 12 Chinese medicinal herbs. The results showed that principal component analysis could be used for a comprehensive evaluation of the quality of Chinese herbal medicines [29]. In 2015, magnetite (Fe_3O_4) magnetic nanoparticles were used as an intermediate carrier for the separation of active agents extracted from *Scutellaria baicalensis* and *Glycyrrhiza uralensis*, thus establishing a new method for the separation and purification of Chinese medicinal herbs [30].

Table 1
Chinese herbal medicines applied in aquaculture, and chemical structures of their main effective ingredients.

Herb name	Effective ingredient	Molecular formula	Structure
Forsythia suspensa	Phillyrin	$C_{27}H_{34}O_{11}$	
Azadirachta indica	Azadirachtin A	$C_{35}H_{44}O_{16}$